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WITNESS my hand this  
Twenty-eighth day of April 2004

A handwritten signature in ink, appearing to be "L. Mynott".

LEANNE MYNOTT  
MANAGER EXAMINATION SUPPORT  
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**PROVISIONAL SPECIFICATION**

*Invention Title:*

*Power management system*

The invention is described in the following statement:

## POWER MANAGEMENT SYSTEM

### Field of the Invention

This invention relates to a power management system and more particularly to a power management system for the supply of power to an implantable medical device, such as an implantable hearing prosthesis. More particularly, it relates to a power management system using a plurality of rechargeable batteries and for controlling the use of the batteries by the prosthesis.

### 10 Background of the Invention

Implantable medical devices, such as cochlea implants, middle ear implants, FES systems and the like, typically consist of two components, one part being an external component commonly referred to as a processor unit and the other part being an implanted internal component commonly referred to as a stimulator/receiver unit. Traditionally both of these components cooperate together to provide a desirable therapy to the implantee. In the case of implantable hearing prosthesis such as cochlear implants and/or middle ear implants, the external component has consisted of a microphone for detecting sounds, such as speech and environmental sounds, a speech processor that converts the detected sounds and particularly speech into a coded signal, a power source such as a battery and an external antenna/transmitter.

The coded signal output by the speech processor can be transmitted transcutaneously to the implanted stimulator/receiver unit situated within the head of the implantee. The transmission can occur through use of an inductive coupling provided between the external antenna transmitter and an implanted antenna/receiver which forms part of the stimulator/receiver unit. The communication serves to transmit the coded sound signal and to provide power to the implanted stimulator/receiver unit. The external part is generally worn outside the skin and can be positioned behind-the-ear like a traditional BTE hearing aid and contains the components mentioned previously.

30 The implanted stimulator/receiver unit typically includes the antenna/receiver that receives the coded signal and power from the external processor component, and a stimulator that processes the coded signal and outputs a stimulation signal to an assembly, which applies the stimulation to generate the desired therapy. In the case of a middle ear implant, the assembly may include a mechanical or hydromechanical

actuator device that is coupled to the ossicles of the middle ear or directly to the inner ear for applying direct stimulation thereto, producing a hearing sensation corresponding to the original detected sound. In the case of cochlear implants, the assembly may include an intra cochlea electrode assembly, which applies electrical stimulation  
5 directly to the auditory nerve producing a hearing sensation corresponding to the original detected sound. The implanted unit is located under the skin inside the mastoid and contains primarily means to demodulate or decode the signals transferred through the skin to drive an actuator or an electrode array and to convert the power transferred through the skin into an electric supply voltage. In known systems the implanted  
10 portion does not contain any independent power source and consequently the transcutaneous link must be in place and therefore the wearer must wear the external component permanently, which impedes the comfort of the wearer.

Due to other particular problems with the external components of existing hearing prosthetic devices, such as the aesthetics associated with wearing a visible  
15 external device, the wearer having to remove the device while showering or engaging in water related activities, and the likelihood that the alignment between the external and internal coils will be lost due to movements during sleep or physical activity, there exists a need to provide a system that allows for total freedom with improved simplicity and reliability. Consequently research has been directed to fully implantable hearing  
20 prosthetic systems that do not require external componentary for the operation thereof. This would include providing a medium-to-long term power source such as rechargeable batteries, in the implants to overcome the need for power to be continually transmitted to the implant from an external power source.

However certain challenges appear with providing implanted devices with such  
25 implanted power sources. Unlike ceramic capacitors used as present-day short-term energy reservoirs, a rechargeable battery degrades irreversibly during its lifetime. They can only undergo a particular maximum number of recharging cycles before the battery performance diminishes to a level where the battery is essentially unusable. The degradation is due to the decomposition of the electrolyte and due to electrode  
30 corrosion. The decomposition of the electrolyte causes the generation of side products like hydrogen and other gases that tend to build up pressure in the battery enclosure and finally escape through flaws in the enclosure. Corrosion of electrodes leads to a reduction of the active surface area and may ultimately cause a short circuit inside the battery through metal spikes growing from one electrode to the other. Both effects lead

to a reduction of the available battery capacity and ultimately to total failure. In the worst case, the implanted battery may rupture causing a severe threat to the health and well being of the wearer. Furthermore, if rechargeable batteries are discharged before being fully charged or conversely charged before being fully discharged, their overall capacity may be prematurely reduced.

Totally implantable hearing systems require a substantial amount of energy to be stored since the whole signal processing unit and supporting functions have to be supplied for a reasonable period of time. In order to be commercially viable, the required autonomy is generally considered as being in the order of a week. On the other hand, the number of recharging cycles of a storage battery is limited. Thus the capacity and ultimate size of an implanted battery must be made as large as possible. However, such application of large batteries causes further challenges, including that they require thick enclosures, that is considered dead space, in order to retain the pressure of invading gases. Large batteries are also prone to the occurrence of internal short circuiting and battery failures are due to their larger surface area. Furthermore, the larger the battery is, the more severe the thermal effect of a battery failure causing thermal damage to surrounding tissue.

The present invention aims to substantially overcome the abovementioned issues by providing a plurality of rechargeable batteries, particularly for a totally implantable hearing prosthesis such that each of the batteries can independently be charged and discharged through a power management system in order to provide for optimum working regimes. The power management system will also comprise a means of controlling the charge and discharge of batteries through switches as well as recognising and disabling failing batteries.

A number of patents related to implanted batteries and charging systems exist such as US Patent No. 6,308,101 to Faltys et al. entitled "Fully Implantable Cochlear Implant System". This patent presents several embodiments of an implanted tissue stimulator such as a cochlea implant, comprising either a rechargeable battery inside the same housing of the implant which solves none of the above-mentioned issues at all, or the so-called "wired" or "proximity systems", where the rechargeable battery is in a second implanted housing and connected to the implanted main unit by means of a subcutaneous electrical plug or a proximity air gap transformer.

International Patent Application Publication No. WO 99/06108 to Schulman et al. entitled "Implantable Device With Improved Battery Recharging and Powering

Configuration" presents substantially the same embodiments of an implanted battery system like the reference above, with the battery electrodes being designed to reduce eddy currents flowing through the bulk of the battery during charging. Furthermore, there exists US Patent No. 6,067,474 also to Schulman et al. entitled

5 "Implantable Device With Improved Recharging and Power Configuration" that describes substantially the same system where an implanted battery together with a signal processor is contained in a separate housing which is not attached to the housing of the implanted processor. Transfer of data and electric power is done by an inductive link. However, once the implanted battery reaches the end of its life the battery

10 requires replacement and the patient must undergo surgery for this to occur. Such repetitive surgery each time the battery needs replacement is undesirable, particularly as the surgery needs to be delicate such as not to affect the sensitive structure and position of the implanted device.

Further prior art is disclosed in US Patent No. 6,227,204 to Baumann et al.

15 which describes a charging system for implanted batteries that control a safe charging mechanism by means of a micro-controller and voltage controlled resistor. This described system is not adaptive to different types of batteries, namely NiMH and NiCd batteries, and as such will result in inefficiently recharged batteries that do not take into consideration the charging requirements of different types of batteries. Furthermore

20 US Patent Application No. 2002/076,071 A1 in the name of Single describes a power management system for a cochlea implant that comprises at least two rechargeable batteries with each battery independently providing power to the system through a switching means. A charge management and monitoring system survey the state of the implanted batteries and decides whether a battery has to be charged or not.

25

#### Summary of the Invention

According to a first aspect of the invention there is provided a power management system for supplying power to an output circuit comprising:

- a plurality of rechargeable batteries;
- 30 first conversion means for converting a supply voltage to a battery voltage to enable charging of one or more of the plurality of rechargeable batteries; and
- switch means to enable a selected battery from the plurality of batteries to be connected to the output circuit to enable the selected battery to be discharged through the output circuit.

The switch means may also be connected to the first conversion means to enable charging to the selected battery. A battery from the plurality of rechargeable batteries may be selected one at a time to provide charge to the output circuit. The system may further comprise a second conversion means connected between the output circuit and the switch means for converting the voltage of the selected battery to a voltage for use by the output circuit thereby discharging the selected battery. The first conversion means may also act as the second conversion means in that charging and discharging of any one of the rechargeable batteries is performed through the same conversion means.

The switch means may comprise a plurality of switches, each switch in the plurality of switches connecting a respective battery to the first conversion means and to the output circuit. The system may further comprise a control unit for controlling the switch means to either enable charging or discharging of a rechargeable battery. The system may further comprise multiplexer means having an input connected to one terminal of each battery to enable the voltage signals pertaining to each battery to be selected and forwarded to an analogue to digital converter.

The system may further comprise shunt impedance means connected to the other terminal of each battery to measure the charge current or discharge current of each battery, represented as a voltage drop across the shunt impedance means. The shunt impedance means may be connected in parallel to a shunt switch to short circuit the shunt impedance means when not in use.

The system may further comprise amplification means connected between the shunt impedance means and the multiplexer means to amplify the voltage drop across the shunt impedance means to the input voltage range of the analogue to digital converter. The analogue to digital converter may measure individual battery voltage of any one of the rechargeable batteries in the plurality of rechargeable batteries and may convert the measured voltage to a digital value. The analogue to digital converter may measure the voltage drop across the shunt impedance means and convert the measured voltage into a digital value.

The system may further comprise a register for storing information pertaining to each battery. The information may comprise any one of more of charge status of each battery, error status of each battery and a flag indicating whether a battery has been disabled from being charged or discharged.

The control unit may be in communication with the register and the analogue to digital converter for processing signals and data from the analogue to digital converter

and from the register. The control unit may periodically sense the presence of a voltage at the input to the switch means. The control unit may select a battery to be charged or discharged on the basis of information stored in the register pertaining to a particular battery.

5       The second converter means may enable discharging of a battery such that charge in the selected battery is forwarded to the output circuit. The output circuit may form part of a medical prosthesis. Preferably the prosthesis is an implantable hearing prosthesis such as a cochlea implant or middle ear implant. The first conversion means may include an inductive means, one or more switch means and a switch control unit to  
10       enable charging and/or discharging of a rechargeable battery. The second conversion means may include an inductive means, one or more switch means and a switch control unit to enable discharging of a selected rechargeable battery. The supply voltage may be derived from an inductive means and rectified into a direct voltage to be applied to the inductive means of the first conversion means.

15       According to a second aspect of the invention there is provided a method of managing the supply of power to an output circuit in a system that includes a plurality of rechargeable batteries, said method comprising the steps of:

      converting a supply voltage to a battery voltage to enable charging of one or more rechargeable batteries of the plurality of rechargeable batteries; and

20       connecting one of the batteries in the plurality of rechargeable batteries, using switch means, to the output circuit to enable the selected battery to be discharged through the output circuit.

      The method may further comprise the step of converting the voltage output from the selected battery to a voltage for use by the output circuit.

25       The method may further comprise the step of providing the switch means in the form of a bank of switches, one for each rechargeable battery.

      The method may further comprise the step of controlling the switch means to enable the charging or discharging of a battery on the basis of information stored in a register on each of the rechargeable batteries. It may further comprise multiplexing and  
30       measuring parameters, such as battery voltage, battery charge and battery current pertaining to each rechargeable battery for storage as digital values in the register.

      The method may further comprise maintaining a record in the register of the state of charge of each rechargeable battery. It may further comprise providing an optimum range, as a percentage value of the state of charge, within which each



rechargeable battery is charged and/or discharged. Where the charge of a battery is above an upper percentage limit of the state of charge of that battery, the method may further comprise the step of disabling charging of that battery. Where the charge of a battery is below a lower percentage limit of the state of charge, the method may further  
 5 comprise the step of terminating the discharging of that battery.

The method may further comprise a means to flag out a battery which was judged as being defective by failing the check for consistency between cell voltage, current and state of charge being determined for each individual battery and to supersede this specific battery for future charging and discharging operations.

10

#### Brief Description of the Drawings

Preferred embodiments of the invention will hereinafter be described, by way of example only, with reference to the accompanying drawings, wherein:

Figure 1 is a block diagram of a power management system for supplying power  
 15 to an output circuit according to a first aspect of the invention;

Figure 2 is a timing diagram showing the charging of two batteries, from a plurality of rechargeable batteries, in the power management system of Figure 1;

Figure 3 is a timing diagram showing the discharging of two batteries from a plurality of rechargeable batteries in the power management system of Figure 1;

20 Figure 4 is an alternative embodiment of a power management system for providing power to an output circuit; and

Figure 5 is a timing diagram showing the charging and discharging of rechargeable batteries in the power management system of Figure 4.

#### 25 Detailed Description of the Preferred Embodiments

With reference to Figure 1 there is shown a block electrical circuit diagram of a multiple battery power supply particularly adapted for an implantable hearing prosthesis such as a cochlea implant, a middle ear implant or a hydromechanical inner ear stimulator. It primarily consists of an input voltage converter circuit 5, an output  
 30 voltage converter circuit 7 and an array of rechargeable batteries 6. An induction coil 1 detects and picks up varying magnetic fields from primary induction coils brought into proximity with the coil 1 and delivers an induction voltage at its terminals. Power transfer at a specific frequency can be made more efficient by optionally including the induction coil in a resonant circuit whereby a capacitor is connected in parallel or series

to the coil 1. A rectifier 2 rectifies the AC voltage generated by the coil 1 or in other words converts the conduction voltage into a DC voltage. The rectifier is shown as a full wave rectifier, however other embodiments such as half way rectifiers or voltage doubling rectifiers are able to be used. A charging capacitor 3 removes the ripple of the rectified voltage delivered by the rectifier 2 and a voltage limiting device 4 absorbs excess voltage generated by the coil 1. After passing through the capacitor 3 and voltage limiting device 4, the DC voltage is passed to an input voltage converter unit 5 which is preferably a step-down (or buck) type. It converts the voltage into an appropriate voltage to charge rechargeable batteries  $B_1, B_2$  up to  $B_n$ . The input voltage converter circuit 5 is primarily made up of a charge switch 5a, an inductor 5b, a discharge switch 5c and a switch control unit 5d. The switch control unit 5d provides control signals to switches 5a and 5c as a function of the desired charge current and saturation current of the inductor 5b. The array 6 of rechargeable batteries comprises one rechargeable battery  $B_1$  and at least one further rechargeable battery  $B_2$  of the same cell chemistry and size. The number of individual batteries is arbitrary. Associated switches  $S_{11}, S_{2n}$  are included in a switch matrix that activates current paths from specific batteries to the input voltage converter 5 and the output voltage converter 7 respectively. The output voltage converter 7 converts the voltage of the rechargeable batteries  $B_1 \dots B_n$  into a voltage appropriate to supply the circuitry of an implant, such as a middle ear implant or cochlear implant. Typically the voltages are between 0.9 volts and 1.5 volts. If a specific battery is connected to the input voltage converter 5, any other switch connecting a battery to the input voltage controller 5 is inhibited in order to avoid parallel connections of batteries. This applies also to the output voltage controller 7 respectively. Connected to each one of the batteries  $B_1 \dots B_n$  between the positive terminal of each battery and its associated switch is a multiplexer 8. The output of the multiplexer 8 is linked to an analogue to digital converter circuit 9 which in turn is linked to a control unit 10. The multiplexer circuit 8 enables each individual positive terminal of the batteries  $B_1 \dots B_n$  to be switched to the input of the converter 9 or alternatively the positive terminal of a shunt resistor 12 connected between the negative terminal of each battery and ground may be directly connected through the multiplexer 8 to the converter 9. The analogue digital converter 9 measures and converts the measured analogue battery voltage of each individual battery and converts it into a digital value which is then supplied to the control unit 10. Alternatively the analogue voltage drop across the shunt resistor 12 is converted into a digital value as

well. The control unit 10 processes signals and data received from the converter 9 and a battery status register 11. The register 11 stores the charge and error status of each individual battery in the array of rechargeable batteries. The control unit 10 thus periodically checks for the presence of a DC voltage at the input of each of the batteries (or corresponding switch) and enables the charging of the batteries by activating the various switches in the switch bank. Preferably, charging is enabled at state of charge or SOC at or below the preset working regime of a used cell chemistry. For example, this pre-set working regime can be between 15% and 95% SOC for nickel metal hydride (NiMH) or between 0% and 80% SOC for graphite/lithium cobaltate cells. The cell chemistry of the batteries determines the charging characteristics applied by the control unit 10. By periodically scanning the voltage and current condition of each individual battery it keeps a record of their SOC, where a fully charged cell has 100% SOC, in the battery status register 11. The control unit 10 can be parameterised in order to support different cell chemistries, for example NiMH, nickel cadmium or NiCd at 1.2V, Li-Ion (graphite/lithium cobaltate 4.2V, lithium titanate- lithium manganese spinel 2.3V) and various cell sizes. It should be appreciated that the cell chemistries and working regimes mentioned above are illustrative examples only and it is envisaged that any suitable implantable battery is included within the scope of the present application, such as solid state systems based on the lithium ion battery or "rocking chair" principle or any other suitable implantable battery based on currently unknown chemical composition. On similar grounds, working regimes which may turn out to be more favourable under certain circumstances are included within the scope of the present application.

The charge current of each individual battery is measured as a voltage drop across the shunt resistor 12 and integrated over time. Thus the resistor 12 generates a voltage drop proportional to the charge/discharge current of each individual battery. The integrated charge for each individual battery is held in the battery status register 11 whose bit vector represents the SOC. If the SOC of the battery is above the optimum regime, the charge process for this battery is disabled and shown as a flag in a battery disable flag field in the register 11. A switch 13 is used to bridge the shunt resistor 12 if not used and a scaling amplifier 14 amplifies the voltage drop across the shunt resistor 12 to a voltage appropriate to the input voltage range of the analogue to digital converter 9.

The control unit 10 controls pseudo-simultaneous charging of all batteries by multiplexing the current paths going through each of the switches  $S_{11}$  up to  $S_{n1}$ . The multiplex cycle ranges from about 1ms up to 10ms multiplied by the number of batteries  $n$ . As a consequence, the breakdown of the energy reservoir into  $n$  batteries  
 5 does not extend the charging time since the overall charging current delivered is  $n$  times the charging current of any individual battery.

Shown in Figure 2 are various timing diagrams showing current versus time of an instance of pseudo-simultaneous charging of two batteries. It is to be noted that any number of batteries can be charged in such a fashion. Switch 5a is closed for a period  
 10 of  $t_1$  which causes the current in inductor 5b to constantly rise. Subsequently switch 5c in the input voltage converter 5 closes for a period of  $t_2$  which causes the inductor 5b to discharge and thereby making the current therethrough decrease. Periods  $t_4$  and  $t_3$  are non-overlapping times that allow the current in inductor 5b to decrease and to avoid parallel connection of batteries due to control signal delays. It is noted that for switch  
 15  $S_{11}$  this is closed to enable current to flow through to battery  $B_1$  and the current in that battery accordingly follows the current profile going through the inductor 5b over the period. The period  $t_3$  is the multiplex period which can be multiples of the inductor charging cycles. Throughout the period  $t_3$  it is noted that switch  $S_{21}$  is open and therefore no current flows through to battery  $B_2$ . Once the second pulse in period  $t_3$   
 20 pertaining to switch 5c closing finishes, in other words at the start of the period  $t_4$  where switch 5c is open there is a delay across that period  $t_4$  for the switch  $S_{11}$  to close. Subsequently, in the next cycle when switch 5a is closed to let current flow through the inductor 5b, switch  $S_{21}$  is closed to enable current to flow through to battery  $B_2$  of which the current profile follows that of the current through inductor 5b in accordance  
 25 with the opening and closing of switches 5a and 5c.

The control unit 10 also controls pseudo-simultaneous discharging of the batteries  $B_1$  through to  $B_n$  in order to optimise the system for an optimum working regime of the batteries. During discharge, the battery associated switches  $S_{12} \dots S_{n2}$ , serve as multiplex switches as well as charge switches for the output converter inductor  
 30 7b. In this case the multiplexing among the switches is controlled by control unit 10 and the duration of the charge time for inductor 7b is controlled by switch control unit 7a. Thus whichever battery  $B_1$  up to  $B_n$  is discharging will have its respective output arm of each switch closed, for example  $S_{12}$ ,  $S_{22}$  up to  $S_{n2}$ . During discharge, the control unit 10 decrements automatically the bit vectors in the battery status register 11

representing the SOC of each individual battery according to the voltage drop across shunt resistor 12. Thus a digital bit value represents the state of charge of each battery at a particular time, whether that battery has discharged or not. If the SOC of any individual battery falls below the optimum regime as discussed above, the discharge  
 5 process of this specific battery is terminated.

In Figure 3 there is shown a timing diagram of current versus time of pseudo-simultaneous discharging of two batteries. Period  $t_3$  is the multiplex rate which can be multiples of inductor charge cycles  $t_1 + t_2$ . Thus it can be seen with switch  $S_{12}$  closed current discharges from battery  $B_1$  increasing up to a point when the switch is opened  
 10 and subsequently in period  $t_2$  switch  $7c$  is closed whereupon the current discharging for battery  $B_1$  decreases to a point when switch  $7c$  opens and switch  $S_{12}$  closes at the end of period  $t_2$ . The current flowing through the inductor  $7b$  follows the current profile discharging from battery  $B_1$ . During all of this time  $t_3$ , the other switches remain open and in particular switch  $S_{22}$  and therefore no current is being discharged from the  
 15 battery  $B_2$  as shown. In the next charging cycle the switch  $S_{22}$  is closed to enable current to be discharged from battery  $B_2$  through the inductor  $7b$  as shown in the next sequence or time period in Figure 3.

The control unit 10 periodically checks for consistency between the voltage and SOC of each individual battery. Each battery features a specific voltage-charge  
 20 characteristic, depending on cell chemistry. If, for instance, a particularly designed Li-Ion cell has a nominal voltage between 3.4 and 3.6V at 50% SOC when discharged with a current of 5mA, consistency is recognised by the control unit 10 if the above conditions are verified. If, for instance, a cell voltage of only 2.5V is verified, corresponding to a typical lowest working voltage of a carbon/lithium cobaltate lithium  
 25 ion battery with a copper current collector used in the negative (carbon) electrode, then control unit 10 judges that the battery is defective and marks a specific battery disable flag in the battery status register 11. As a consequence, the battery is being kept isolated for the rest of its lifetime and is omitted from charging and discharging cycles.

A further embodiment of the invention is shown in Figure 4. Like reference  
 30 numerals apply as in Figure 1. The main difference between the embodiments shown in Figure 4 and Figure 1 is that in Figure 4 a different switching arrangement allows a reuse of the original input voltage converter inductor  $5b$  for the output converter as well. In other words rather than using the inductor  $7b$  in the output voltage converter circuit 7 of Figure 1, this is now incorporated into a single inductor  $5b$  for input and

output conversion of voltages. Thus both terminals of the inductor 5b are respectively connected to the implant circuit, such as an implantable hearing prosthesis circuit such as a middle ear implant or cochlear implant, through respective switches 5d and 5f. A switch control unit 5e controls the switches 5a, 5c, 5d and 5f.

5 The main reason for using a single inductor for input and output voltage conversion is that inductors are generally bulky and consume a lot of space on a circuit board and are generally expensive devices in comparison to other devices. Particularly in implantable devices, space is scarce and therefore a refined embodiment is utilised in the circuit arrangement of Figure 4. During charging, the inductor 5b can be used  
10 simultaneously for both converting the input voltage to charge the batteries B<sub>1</sub> up to B<sub>n</sub> and for converting the battery voltage to feed the cochlea implant circuit. An uninterrupted power supply of the implant circuit is granted through dispersing discharge cycles and charge cycles. The functions of the other components shown in the circuit arrangement of Figure 4 are similar to those as in Figure 1.

15 With reference to Figure 5 there is shown a timing diagram of current versus time of a period of operation of the input/output converter switches where, for instance, battery B<sub>1</sub> is charged through switch S<sub>1</sub> and battery B<sub>2</sub> is discharged through switch S<sub>2</sub>.

As can be seen in Figure 5 with switch 5a closed it allows current to flow through the inductor 5b, indicated by current I<sub>L</sub> and switch S<sub>1</sub> is closed thereby  
20 charging battery B<sub>1</sub>. The switch 5a is closed during the time interval t<sub>1</sub>, and the switch 5c is opened during time interval t<sub>1</sub>. At the end of time interval t<sub>1</sub>, i.e. at the beginning of time interval t<sub>2</sub>, the switch 5a will be opened and the switch 5c closed. The current through the inductor 5b is slowly discharged to ground during t<sub>2</sub>, however switch S<sub>1</sub> remains closed until time t<sub>3</sub> expires when the switch 5c is open again. A new charging  
25 or discharging cycle then starts after time t<sub>4</sub> whereby switch 5d is closed as is switch S<sub>2</sub>. Thus battery B<sub>2</sub> is discharging current through the inductor 5b in a reverse direction to be output to the implant circuit. Thus the current I<sub>L</sub> being the current through the inductor 5b is shown with a negative polarity increasing to when switch S<sub>2</sub> is open. At this time switch 5f is closed thereby discharging the current I<sub>L</sub> back to ground. Thus  
30 switch 5d remains closed for the duration of the sum of the time that switch S<sub>2</sub> and switch 5f collectively are closed.

It will be appreciated by persons skilled in the art that numerous variations and/or modifications may be made to the invention as shown in the specific embodiments without departing from the spirit or scope of the invention as broadly  
35 described. The present embodiments are, therefore, to be considered in all respects as illustrative and not restrictive.

THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:

1. A power management system for supplying power to an output circuit  
5 comprising:
  - a plurality of rechargeable batteries;
  - first conversion means for converting a supply voltage to a battery voltage to enable charging of one or more of the rechargeable batteries; and
  - switch means to enable a selected battery of the plurality of rechargeable  
10 batteries to be connected to an output circuit to enable the selected battery to be discharged through the output circuit.
2. A system according to claim 1 wherein the switch means is connected to the first conversion means to enable charging to the selected battery.  
15
3. A system according to claim 1 or claim 2 further comprising second conversion means connected between the output circuit and the switch means for converting the voltage of the selected battery to a voltage for use by the output circuit thereby discharging the selected battery.  
20
4. A system according to any one of the previous claims wherein a rechargeable battery may be chosen, one at a time, in order to be charged or discharged.
5. A system according to any one of the previous claims wherein the first  
25 conversion means acts as the second conversion means.
6. A system according to any one of the previous claims wherein the switch means comprises a plurality of switches, each switch connecting a respective rechargeable battery to the first conversion means and to the output circuit.  
30
7. A system according to any one of the previous claims further comprising a control unit for controlling the switch means to either enable charging or discharging of a rechargeable battery.

8. A system according to claim 7 further comprising multiplexer means having an input connected to one terminal of each rechargeable battery to enable the voltage signals pertaining to each battery to be selected and forwarded to an analogue to digital converter.
- 5 9. A system according to claim 8 further comprising a shunt impedance means connected to the other terminal of each battery to measure the charge current of each battery, represented as a voltage drop across the shunt impedance means.
- 10 10. A system according to claim 9 wherein the shunt impedance means is connected in parallel to a shunt switch to short circuit the shunt impedance means when the shunt impedance is not in use.
11. A system according to claim 10 further comprising amplification means  
15 connected between the shunt impedance means and the multiplexer means to amplify the voltage drop across the shunt impedance means to the input voltage range of the analogue to digital converter.
12. A system according to claim 11 wherein the analogue to digital converter  
20 measures individual battery voltage of any one of the rechargeable batteries in the plurality of rechargeable batteries and converts the measured voltage to a digital value.
13. A system according to claim 11 or claim 12 wherein the analogue to digital  
25 converter measures the voltage drop across the shunt impedance means and converts the measured voltage into a digital value.
14. A system according to claim 13 further comprising a register for storing information pertaining to each battery.
- 30 15. A system according to claim 14 wherein said information comprises any one or more of charge status of each battery, error status of each battery or a flag identifying whether a battery has been disabled from being charged or discharged.



16. A system according to claim 15 wherein the control unit is in communication with the register and with the analogue to digital converter for processing signals and data from the analogue to digital converter and from the register.
- 5 17. A system according to claim 16 wherein the control unit periodically senses the presence of a voltage at the input to the switch means.
18. A system according to claim 17 wherein the control unit selects a battery to be charged or discharged on the basis of information stored in the register pertaining to a  
10 particular battery.
19. A system according to any one of the previous claims wherein the second conversion means enables discharging of a battery such that charge in the selected battery is forwarded to the output circuit.
- 15 20. A system according to claim 19 wherein the output circuit forms part of an implantable device.
21. A system according to claim 20 wherein the implantable device is an  
20 implantable hearing prosthesis.
22. A system according to any one of the previous claims wherein the first conversion means includes an inductive means, one or more switch means and a switch control unit to enable charging and/or discharging of a selected battery.
- 25 23. A system according to any one of the previous claims wherein the second conversion means includes an inductive means, one or more switch means and a switch control unit to enable discharging of a selected battery.
- 30 24. A system according to any one of the previous claims wherein the supply voltage is derived from an inductive means and rectified into a direct voltage to be applied to the inductive means of the first conversion means.

25. A method of managing the supply of power to an output circuit in a system that includes a plurality of rechargeable batteries, the method comprising the steps of:  
converting a supply voltage to a battery voltage to enable charging of one or more of the plurality of the rechargeable batteries; and  
5 connecting a battery in the plurality of rechargeable batteries, using switch means, to the output circuit to enable the battery to be discharged through the output circuit.
26. A method according to claim 25 wherein the selected battery is discharged to the  
10 output circuit by converting the voltage output from the selected battery to a voltage for use by the output circuit.
27. A method according to claim 25 or claim 26 further comprising the step of providing the switch means in the form of a bank of switches, one for each  
15 rechargeable battery.
28. A method according to claim 27 further comprising the step of controlling the switch means to enable the charging or discharging of a selected battery on the basis of information stored in a register on each of the rechargeable batteries.  
20
29. A method according to claim 28 further comprising the steps of multiplexing and measuring parameters, such as battery voltage, battery charge and battery current, pertaining to each rechargeable battery for storage as digital values in the register.
- 25 30. A method according to claim 29 further comprising the step of maintaining a record in the register on the state of charge of each rechargeable battery.
31. A method according to claim 30 further comprising the step of providing an optimum range, as a percentage value of the state of charge, within which each  
30 rechargeable battery is charged and/or discharged.
32. A method according to claim 31 further comprising the step of disabling charging of a battery where the charge of that battery is above an upper percentage limit of the state of charge.

33. A method according to claim 31 or claim 32 further comprising the step of terminating the discharging of a battery where the charge of that battery is below a lower percentage limit of the state of charge.

Dated this eleventh day of April 2003

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**F B RICE & CO**

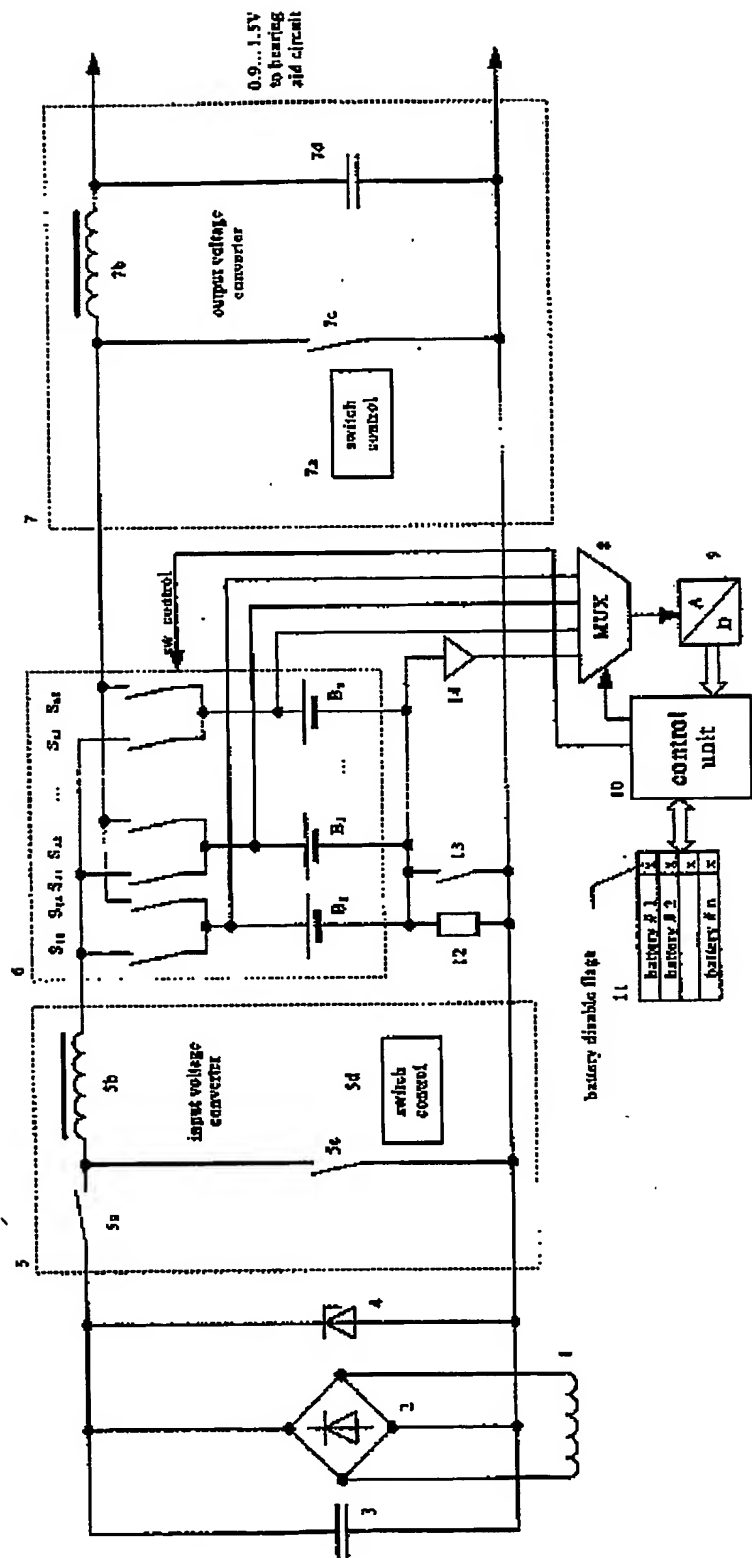


Figure 1

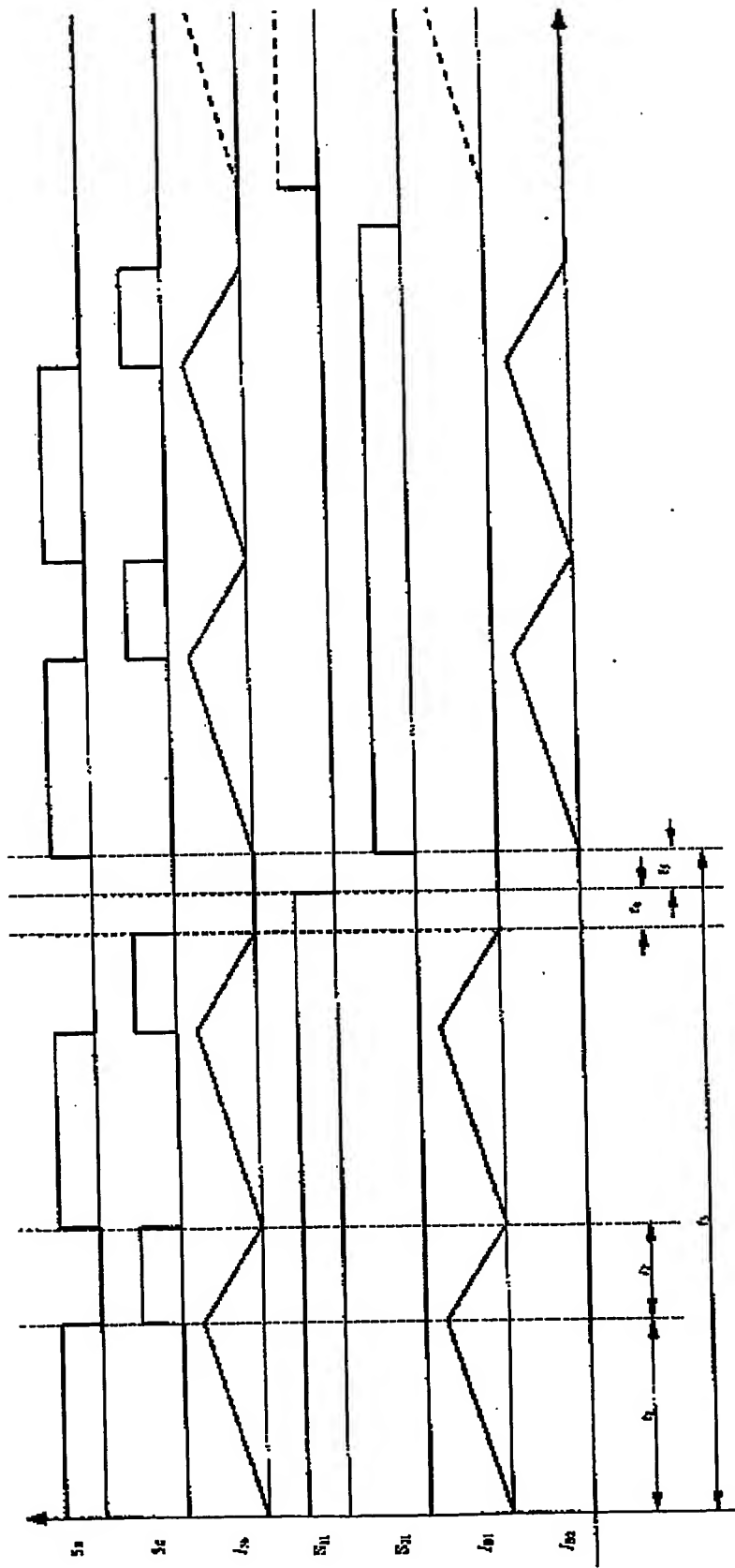


Figure 2

For clarity - logic "high" means "switch closed"

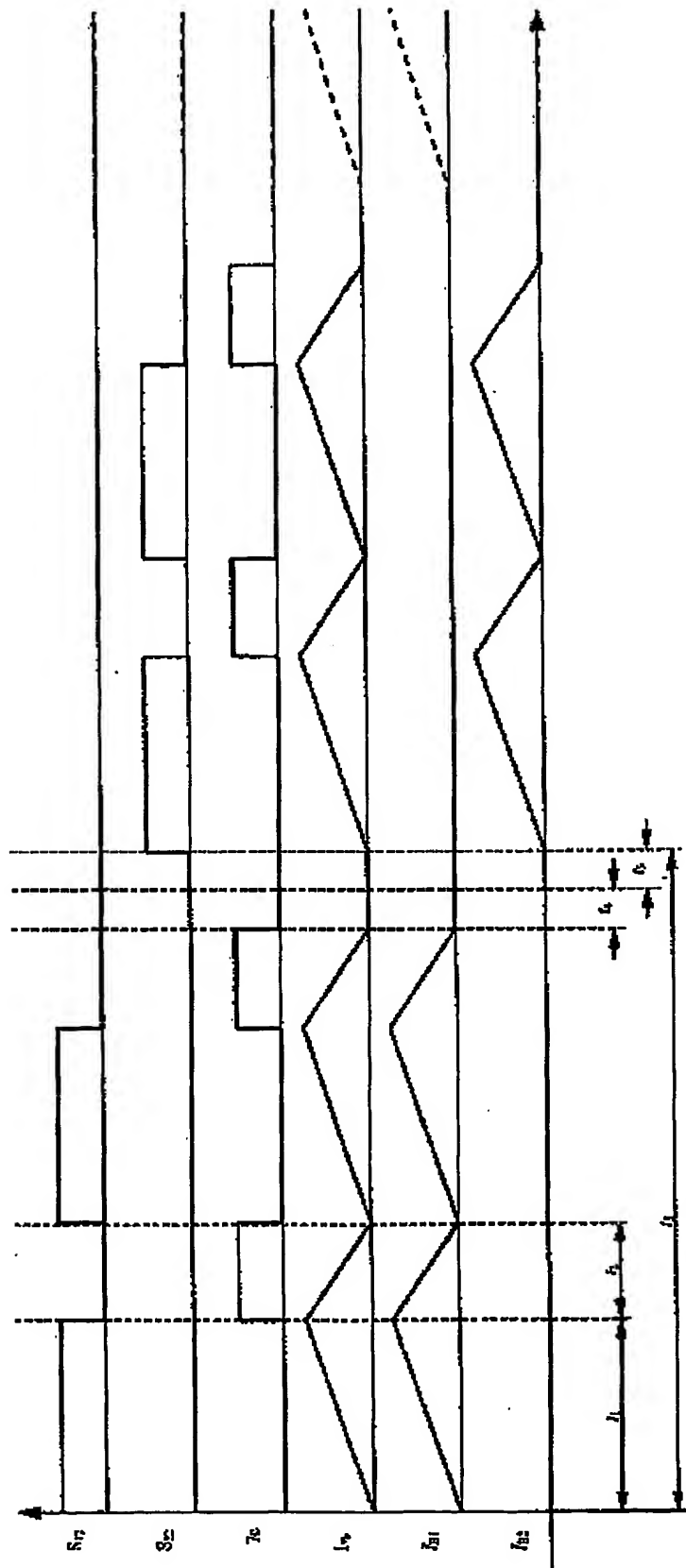


Figure 3

For clarity - logic "high" means "switch closed"

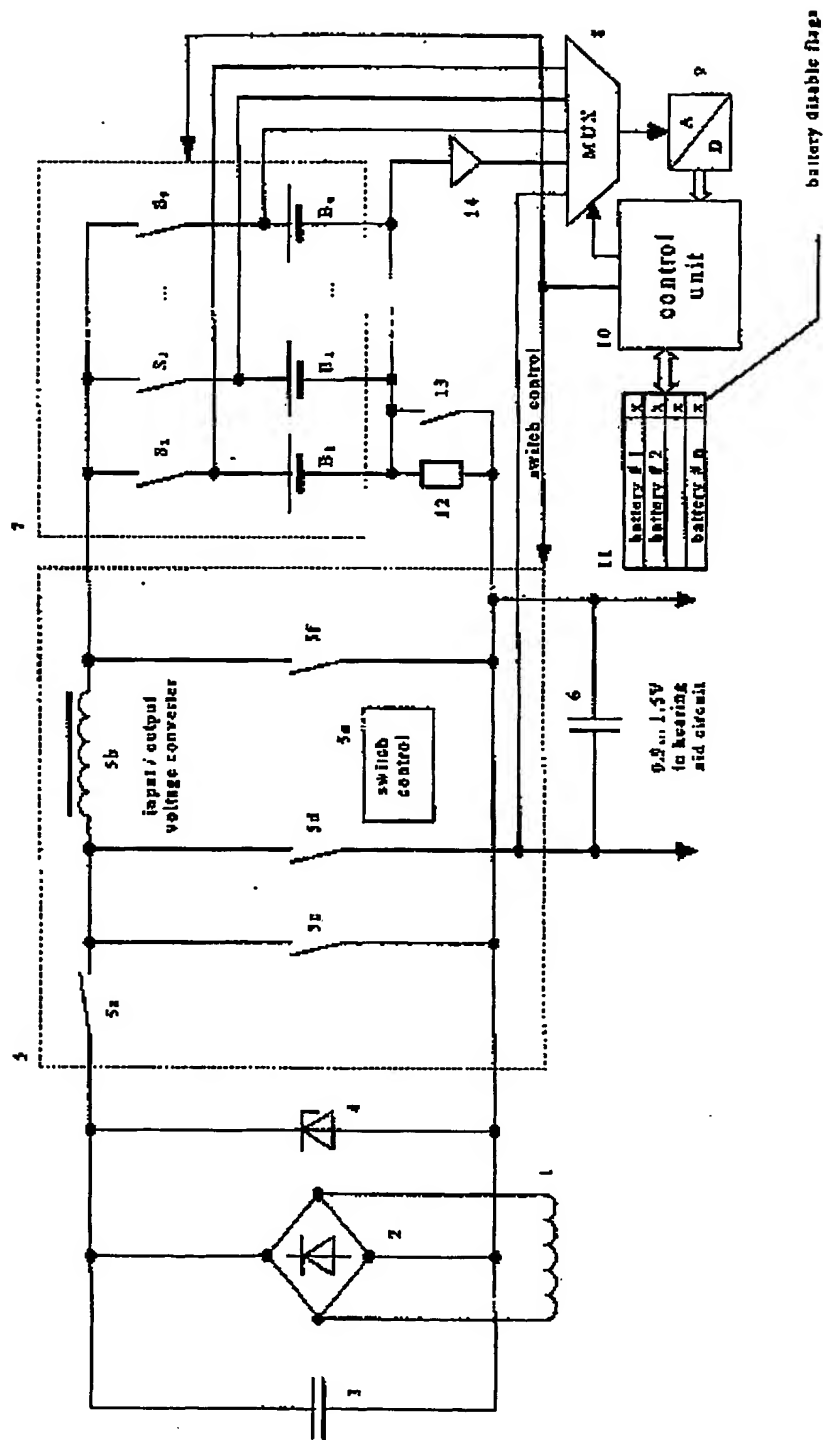
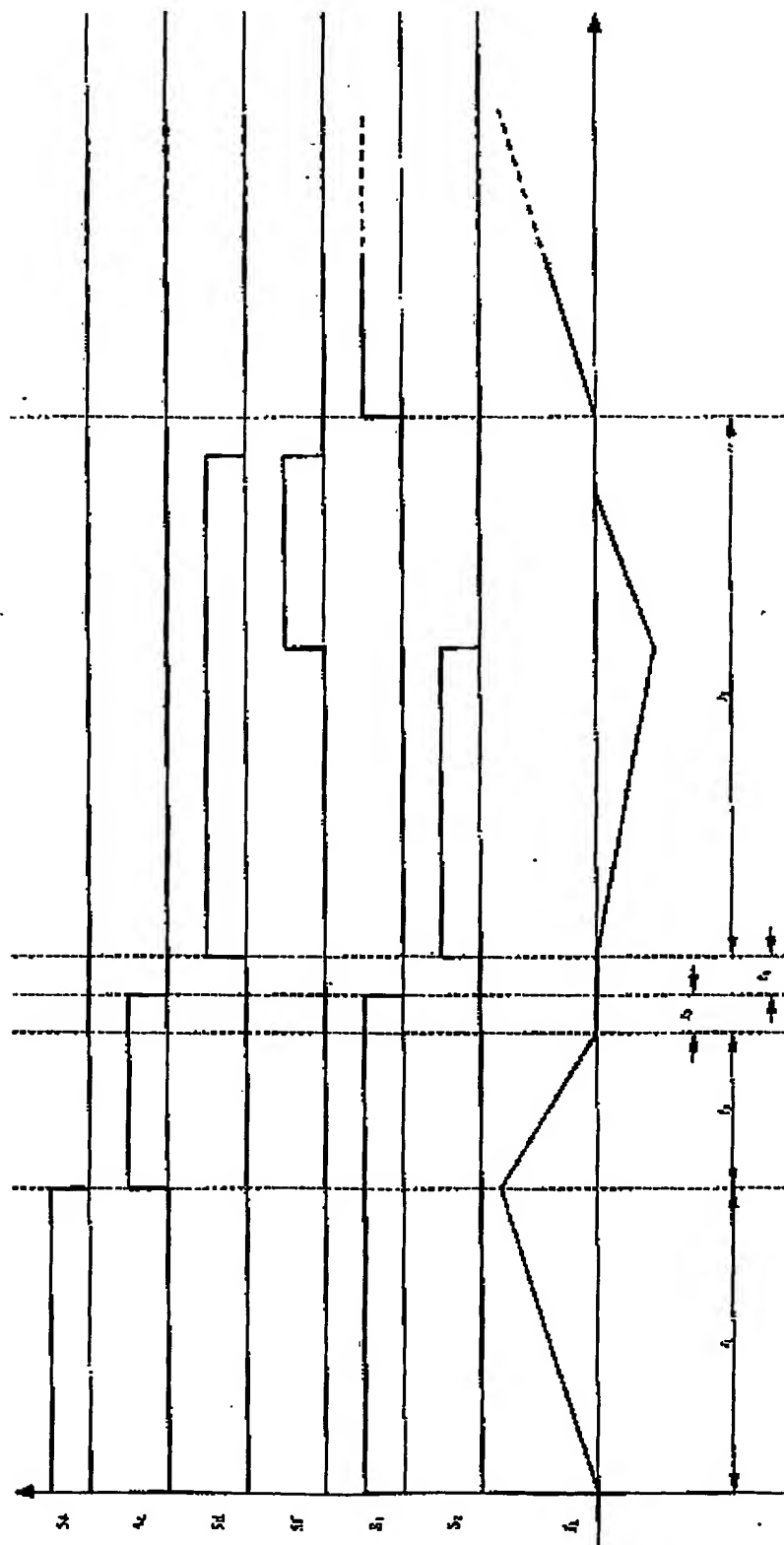


Figure 4



**For clarity - logic "high" means "switch closed"**